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DEPARTMENT of PSYCHOLOGY

PREDICTING HUMAN PERFORMANCE III: THE DETECTION OF A SIMPLE VISUAL SIGNAL AS A FUNCTION OF TIME OF WATCH

WARREN H. TEICHNER

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Warren H. Teichner

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13. ABSTRACT

The percentage of detection of 37 studies of vigilance, using simple signals, were found to depend primarily on the initial or pre-test detection level, the nature of the signal, i.e. whether it is a dynamic signal (requires movement or change of state of the eye) or static, and the duration of the watch. The loss of detection associated with static signals was assumed to be more representative of a loss in a "vigilance" or attentional process. That loss appears to be rapid in development, essentially complete in about 35 min., and small in amount. The greater decrements associated with dynamic stimuli were assumed to be due to an additional process of eye fatigue.

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PREDICTING HUMAN PERFORMANCE III.

THE DETECTION OF A SIMPLE VISUAL SIGNAL AS A FUNCTION OF TIME OF WATCH

This report is our third which uses the scientific literature as a basis for developing quantitative principles of human performance. In this study we were concerned with what are usually described as vigilance or monitoring tasks. As with our previous efforts (Teichner and Krebs, 1972a, 1972b), we started by assuming that there are no differences in the effects of variables which have been studied and demanded that the literature demonstrate that such effects as are claimed hold quantitatively when the different experiments that have been reported are plotted on a single graph. If a single function can be found which can be plotted reasonably through the results of varying kinds of experiments, then our assumption has been that the differences between these experiments including those due to the use of different experimental variables and procedures are, at best, small. If such a function cannot be found, then our procedure has been to seek one or more functions, using the smallest possible number of variables and parameters, which do hold across experiments. If no functions can be found which can be used across experiments then it is necessary to conclude that the data, and, therefore, the literature involved are not reliable enough to establish a basis for predicting absolute values. Our interest then turns to the question of why that may be.

The topic of vigilance has had a fairly long and very active research interest. Within the context of human performance prediction, it arose in response to questions about the effectiveness with which radar operators could carry out prolonged watches. Norman Mackworth's ingenious experiments with the jump clock (1950) suggested that the probability of detecting a simple signal decreases with time on watch and that the decrease could be magnified or reduced by a variety of task variables, signal characteristics, and personal, (including motivational) variables. His original proposal to explain the loss of ability to detect the signal with time was framed within the context of conditioning theory, particularly the reactive inhibition concept of Hull (1949). Since that study and its theoretical proposal, a large number of investigators have studied the problem. A variety of methodologies have evolved and theoretical explanations have been proposed. Indeed, it appears that the vigilance function has had applied to it in succession, enough of the major theoretical concepts of experimental psychology of the last 25 years

that the literature on the topic stands almost as a kind of historical guide. But, in testimony to how little is actually understood about what is going on during the time of watch is the success with which all of these theories can account for the decremental function. Unfortunately, the decremental function itself, is more presumed than established. In fact, theoretical interest seems to have run so far ahead of the data, and of the development of quantitative empirical relationships that the original question concerning the effects of duration of watch on the effectiveness of signal detection seems to have been all but forgotten by many investigators.

It is not our intention to review the field of vigilance in this paper since as a topic it has been reviewed very frequently and in depth(e.g. Broadbent, 1958, 1971; Davies and Tune, 1970; Deese, 1955; Frankman and Adams, 1962; Jerison and Pickett, 1963; Loeb and Alluisi, 1970; Mackworth, 1968; Swets and Kristofferson, 1970). Of those reviews, that of Davies and Tune (1970) is the most comprehensive.

The present study was restricted to simple situations having visual targets in essentially noiseless environments. It was also restricted to the case where only one kind of target or signal is used and where there is minimal uncertainty about the position in space at which the target will appear. We did allow for positional uncertainty within a small confined area such as a radar screen or a clock face. Such situations have minimal positional uncertainty since they impose a directed search of a small area, or, and more generally, they require monitoring of a moving signal for occasional changes in its behavior. Studies of free positional search were excluded. Thus, the primary unknown to the subject in the experiments used is exactly when, rather than where, the signal will appear.

Although our interests were confined to the least complex situations, it appears that those are the situations in which decrements have been reported most frequently (Frankman and Adams, 1962). More complex situations, those that involve a multiple of targets and/or extraneous or noisy elements tend to be less susceptible to decrement with time on watch. It is the simpler situation , therefore, which has the most practical concern and theoretical interest. An exception may be the dual vigilance task in which the subject is required to monitor more than one signal source simultaneously and to respond to both signals when they occur. Experiments of this kind are not included since they exceeded the scope of the present study.

This investigation was also restricted to the use of the percentage or proportion of signals detected as a dependent measure. There are, of course, reports of detection time in the vigilance literature. In our framework of investigation, however, such measures imply a different task or process than is implied by the proportion of detections. They will be dealt with in a later report.

Our data source was the vigilance literature published between 1950 and 1971. Methodological information was extracted from the studies available. From those which appeared to be adequate methodologically, we also extracted the actual data. Methodological adequacy in this case meant that sufficient detail about the characteristics of the signal and of the procedures used were presented to allow inter-study comparisons, and that the experimental procedures provided for appropriate controls and experimental design. What is appropriate, of course, is subject somewhat to individual opinion. For reasons to be indicated below, we were forced to conclude that according to our criteria, there are no really acceptable studies available. As a result we were forced to alter our criteria of acceptability and to make some assumptions about the studies in order to find a way to compare them.

Methodological Approaches and Weaknesses

The original task used by Mackworth (1950) involved a large clock-type face with a single pointer. The pointer moved in discrete steps or jumps around the clock face and occasionally skipped a step, that is, it double jumped. The double jump was the signal which the subject was required to detect. This kind of apparatus has been used since by a number of other investigators. Still others have used situations involving flashes of light in a dark background, deflections of an oscillating pointer, pauses in a continuously sweeping clock hand and others. The particular methods employed by the studies whose data we shall present are listed in Table 1.

It is apparent from Table 1 that a variety of signal types have been used, and that they could be placed into two major classes: (1) those that require detection of the presence of an event in an otherwise homogeneous field, and (2) those that require a discrimination between the recurrent behavior of a stimulus event and an infrequent or unusual behavior of that event. On the other hand, the signal types might be categorized into (1) those that involve static or stationary events and (2) those that involve

3.b

TABLE 1.

SIGNALS USED IN THE PRESENT ANALYSIS AND CODE CATEGORIES
FOR THE FIGURES TO FOLLOW

Code Category	Signal Type
Open symbol, such as ○ □	Orange light spot
Open symbol, such as ○ △	White light spot
Open symbol, such as ○ ▽	Radar pip
Completely closed symbol, such as ● ⬢	Interruption of continuous white light
Completely closed symbol, such as ● ■	Interruption of continuous red light
Symbol with lower half closed, such as ◒	Change in brightness of dim-bright cycling light
Symbol with lower half closed, such as ◒	Brightness increment of steady light
Symbol with right half closed, such as ◑ ◨	Brightness increment of flashing light
Symbol with right half closed, such as ◑ ◮	Brightness decrement of flashing light
Symbol with right half closed, such as ◑ ◨	Increase in duration of flashing light
Open symbol with pips, such as ○ □	Brightness increase of one of three simultaneous flashing tubes
Roman numerals, such as II	One disc "paler" than other five on a card
Small letters, such as a b	Disc of greater size than standard disc
Symbol with upper half closed, such as ◓ ⬒	Movement of a point source of light
Capital letters, such as A	Increase length of deflection of light bar
Open symbol circumscribing an X, such as ⊗ ⊠	Double deflection of light bar
Open symbol circumscribing an X, such as ⊗ ⊗	Deflection of pointer past mid-dial position
Open symbol circumscribing an X, such as ⊗ ⊠	Deflection of pointer greater than standard deflection
Symbol with left half closed, such as ◐ ◧	Double jump of stepping clock hand

TABLE 1 (CONT)

Code Category	Signal Type
Symbol with left half closed, such as ◐ ◭	Failure of lamp to illuminate in sequence
Symbol clcsed in two portions, such as ⨂ ⧗	Double jump of light spot
Greek letters, such as β θ	Pause in movement of a sweeping clock hand

moving or dynamic events. In the second class one might (or might not) wish to place intermittent or flickering lights even though no motion is involved.

Originally, both vigilance and monitoring performances were assessed in terms of the proportion or percentage of signal detections. In more recent years the indices of the theory of signal detection (TSD) have found increasing application as dependent measures. As with psychophysical measurement, the primary argument for the use of TSD is that it takes into account both the probability of hits and of false alarms (FA) whereas the traditional method provides only the probability of hits.

The earlier studies reported a loss in the proportion of detections with time. Studies using TSD agree, but also suggest a concurrent decrease in FA. As a result d' tends to remain constant with time. The explanation of these phenomena that has been offered is that β increases, i.e. that the subject increases his criterion or definition of what event is a signal or, in other terms, becomes more cautious in responding. His sensitivity to the signal, however, as measured by d' is not affected. The entire problem is reviewed in depth by Swets and Kristofferson (1970) who also conclude, largely from studies by J. Mackworth, that d' decreases only at very high observing rates as would be demanded by rapidly alternating pointers or frequent pauses in a continuously sweeping clock hand.

Swets and Kristofferson also point out major difficulties in the application of TSD to vigilance data. Very importantly they note that the typical study produces a very low FA rate. As a result, values of d' and β may be in serious error. To circumvent this, they suggest using weak signals and, thereby, increasing the FA frequency. Such a procedure would move the vigilance experiment in the direction of a psychophysical or sensory study. While doing that may increase the meaningfulness of using TSD, it changes the original question which concerned the loss of detection of a signal which is normally (e.g. during a pre-test) reported with few misses and few or no FAs. As an extension of the original question, however, it does seem to have practical value, for example, in application to the detection of targets in low illumination such as by personnel in the field, survivors at sea, etc. On the other hand, if possible, it would be more useful to have just one analytic framework within which vigilance might be handled regardless of signal intensity.

Another difficulty indicated by Swets and Kristofferson concerns the fact

that most vigilance studies have provided the subject with little or no practice before running for record. Generally, the subject is given a short practice or orientation period with signals at a much higher rate than to be used subsequently. Following that, he is used for only one or two test sessions. In spite of this, as noted above, few FAs are made.

Not only are few FAs made in the usual vigilance study, but their presence when they do occur may simply reflect insufficient practice (Elliot, 1960). Given that possibility, and the liklihood that when FAs are made, they tend to occur only when the signal rate is very high or when the signal is very weak, TSD does not really appear to be importantly applicable to the vigilance problem.

Finally, a fundamental assumption of TSD is that the subject optimizes correct detections and minimizes FAs and that he does this on the basis of an exact knowledge of the signal probabilities. It is not likely that the experimental procedures used allow the subject to establish even moderately well-developed subjective probabilities. The importance of this assumption in a related context has been demonstrated recently by Parducci and Sandusky (1970). Given this theoretical requirement and the observation above, we conclude that TSD is not appropriate for analysing vigilance data. We have excluded such measures from this study, therefore.

In what ways could the subject improve with practice in the vigilance task? At least two studies (Teichner, 1962; Mackworth, 1963) report a considerable decrease in the proportion of missed signals with practice. Since FAs are minimal, it would seem that <u>with practice the subject learns how to observe</u>. But we also suspect strongly that with practice, each succeeding session is attended to with a reducing motivation. This hypothesis is based strictly on the introspective reactions of the author following a number of experiences serving as a subject in such experiments. If the hypothesis is reasonable, it suggests that there is an optimal amount of practice since with repeated practice sessions, the beneficial effects of the practice may be overcome by the detrimental effects of the lowered motivation. In fact, still reporting on an introspective basis, the subject may adopt some kind of rate of response criterion and be willing to miss signals when their frequency is so high as to demand that he respond at a rate higher than the criterion.

In spite of the conclusion that there may be an upper limit to the amount

of practice which is desirable, and the implicit suggestion that the optimal amount may be small, the amount of practice given in the studies available still seems to be much too little. As a general criticism of the research that has been done, we are forced to suspect that the actual results obtained are badly confounded with the problem of practice and motivation. The situation is not unlike that faced by researchers in the field of taste preferences, and it may be necessary to approach vigilance with some of the same kinds of methodological questions. With this in mind, the analysis that follows necessarily ignored the issue which is to say that the data used are considered to be weak in the sense indicated.

Another general criticism of the vigilance research available has to do with the fact that with few exceptions, the detectibility of the signal under non-vigilance conditions is never specified. Some authors have reported pre-test levels of detection, but generally, the pre-test value is obtained from tests made on other subjects at other times, or if made on the subjects used, they are values obtained with little attention to needs for experimental controls. The truth of that harsh statement lies in the simple observation that pre-test values of the percent of detections are sometimes grossly exceeded during the vigilance period.

Here again we are faced with a methodological problem. Obtaining a reliable pre-test detection level imposes an experimental period on the subject which may have the same effects as practice, i.e. the subject's motivation may be reduced during the subsequent test period. We know of only one attempt to cope systematically with the pre-test issue (Teichner, 1962). That study used a brief light as the signal and experimentally manipulated its luminance according to percentages of detection obtained from each subject in a psychophysical session immediately preceding the watchkeeping activity. The results were clear in showing that the percentage of detections at any time during the vigilance period depended upon the percentage of detections used to define the signal intensity. However, perhaps because of reduced motivational levels, the losses in performance over time obtained in that study were far greater for all signals than is usually reported for that particular vigilance test. As a result, the study was not used in the analysis to follow. Nevertheless the method used, that of pre-defining the signal in terms of the dependent measure to be used, is strongly recommended providing that the possible problem of motivational control can be solved.

Our last general criticism of available vigilance research concerns the intervals of time over which investigators have obtained and summarized their data. It is not unusual for the reported measure to be the percentage of signals detected in each 10-min, 20-min, or 30-min period. Since as a general conclusion most of the decrement occurs in the first 30 min of the watch, measures based on 10-30 min intervals tend to hide that part of the curve showing the most rapid changes.

Once again it must be pointed out that obtaining measures over such time periods is forced by methodological considerations. At least two signals are required to obtain a percentage of response in the first place. Yet, in some cases, the signal frequency has been so low that long data averaging times were required just to get a response measure. When, at the same time, the pre-test signal strength is not defined and therefore, normal performance is not known, it becomes very difficult, if not impossible to find a trend which starts at that point of time at which the vigil began. In fact, without knowing the pre-test or initial percentage of detection (IPD) it is difficult to separate the vigilance performance level from the non-vigilance performance and it is impossible logically to compare the results of different experiments even when the same time periods are used.

Analytic Methods and Results

As a final data base with which to work, we had available the results of 37 studies. Some of those studies contained more than one set of data. Almost all of them were deficient in specifying critical experimental conditions. Many of them were accepted for use simply because otherwise we would have had little left with which to work. Finally, it seems to be a characteristic of this literature that it has not overcome the ambiguities of its methodology in a descriptive sense. We had a great deal of difficulty untangling what authors were attempting to state as the conditions that they employed. In particular, authors were unclear when they attempted to describe the "probability of occurrence" of the signal, the signal rate, the non-signal rate, and the inter-signal interval.

To some degree the confusion in describing the methods used was due to difficulties inherent in the methods themselves. For example, consider the kind of experiment which uses a sweeping clock hand for which the signal is a brief pause in the movement of the hand. The two events are moving hand, and

non-moving hand. If the hand pauses, say, three times per min and if the rate at which it moves is one revolution per second (i.e. it makes one revolution in one second if it does not stop), what is the signal probability? What would the signal probability be if the sweep rate were doubled? One possible way to define it might be to consider a packet of time as having a signal or non-signal (i.e. empty interval) and then to define the probability of a signal as the ratio of signal intervals to non-signal intervals. In that case, the signal probability is identical to the signal rate; nor does the situation change if revolutions are used. In either case, the selection of a time packet, or the number of revolutions to use as a referent is arbitrary and, consequently, the specification of the probability and of the rate is arbitrary. The problem would not be serious if it were not for the fact that other situations having definite non-signal events, such as an alternating pointer, cannot be compared parametrically.

In reporting vigilance experiments other difficulties arise which are associated with attempts to distinguish the task used from other tasks or to relate it to some theoretical approach. For example, Broadbent,(1971) describes some events as signals and others as carrier signals. The sweeping clock hand and the alternating pointer are examples of carrier signals. This distinction appears to be useful until one attempts to find a situation without a carrier signal. When the signal is a light flash, is the unlit lamp a carrier signal? Our point is not intended to suggest that the term carrier signal is not useful where it may apply, but only that it does not have general terminological value.

On the other hand, some term is needed to distinguish between signal and non-signal events regardless of whether the latter are carrier signal events or irrelevant or distracting stimuli. For our purposes we have found it helpful to view all events to which the subject could respond as stimuli and those stimuli to which he should respond as signals. The distinction is especially useful for distinguishing signal rates and signal probabilities from non-signal stimulus rates and probabilities.

RESULTS

The results of all 37 studies were plotted as a function of time of watch without regard to any other experimental considerations. The resulting figure approximated a zero correlation scattergram and provided no suggestions toward

subgrouping of the studies. Attempts were then made to sort the studies into classes of approximately equal value with respect to signal rate, signal probability, signal duration, and event rate and probability. Although these variables did appear to have shown effects in some experiments, the effects were never very consistent across experiments and that was especially true for comparisons in terms of absolute values.

Attempts were made to reduce the amount of data by eliminating studies which reported dependent measures only at long time intervals, e.g. every 30 min. Doing that increased the ambiguity, if anything, since it tended to reduce the length of the watch available for use as an independent measure and drastically reduced the number of studies.

Attempts were made to carry out the above analyses, but restricted with respect to class of signal. For example, all studies using a flash of light as a signal were considered separately. While doing that did increase the consistency among studies somewhat, it still did not provide suggestions of reasonable functional relationships.

Finally, as noted above, it was decided that the major difficulties with the data resulted from the fact that there were few instances in which a pre-vigilance testing detection level was reported, and of those reported, few if any, that were acceptable. It was decided, therefore, to attempt to estimate the pre-test levels from the vigilance data. That was done by selecting a specific time after the beginning of the watch and assuming that the largest detection proportion reported up to that time was equal to or greater than the normal or pre-test value. The first time interval criterion selected was 5 min. This meant that only studies could be used which reported a detection measure within 5 min. Since very few of the studies available did that, it was necessary to increase the criterion time. On this basis we were not able to retain very many of the studies until we established 30 min as the criterion Thus, the largest detection value reported within 30 min was used as the pre-test measure.

Partly, to reduce the liklihood that the pre-test level was greater than the post-test value used and partly to reduce the remaining variability among experiments, the pre-test assignments were made to class intervals which had an interval range of 10 percent. For example, a study whose largest percentage of detections reported in the first 30 min was 72 was assigned to the pre-test grouping of 70 to 79 percent. A study with a largest value of 84 percent was assigned to that group for which the pre-test level varied from 80 to 89

percent. On this basis the studies available were found to require class intervals from 30 to 39 percent to 90 to 99 percent. The results are shown as the data points in Figures 1 to 7. For reasons which will be indicated, these figures do not include data from the sweep clock.

Figure 1 presents percent detection as a function of time of watch for the 90 to 99 percent pre-test level. Looking only at the data points, it is apparent that there is a decreasing detection level as the length of the watch increases. The center line of the figure represents a best fit made by eye to the data. The relationship is slightly curved initially, but linear between 10 and 120 min. The curve appears to have an asymptote at 70 percent. Figures 2 through 6 which represent successively decreasing pre-test class interval levels are essentially similar to Fig. 1 although the number of data points vary and no decrement is suggested for the 30 to 39 percent interval.

Each of the center lines in Figures 1 through 7 was fitted independently, that is each line was fitted without regard to previous fitting procedures. If those center lines are transferred to a single graph, their similarities may be assessed. Figure 8 provides such a plot. Figure 8 shows that there are some important similarities among the curve fits. First, the maximum decrement is fairly small in all cases. Although some of the curves appear to have the same asymptotes, the general impression is of a family of negatively accelerated, decreasing functions. If, in fact, it is assumed that the curves are all identical except for their Y-intercepts, and if it is assumed that the pre-test levels (t=o) are best represented by the centers of the class intervals, the family of curves may be smoothed by spacing the asymptotes and having each curve pass through the center of the interval The result of doing that is shown in Figure 9. Figure 9, then, provides an idealized version of Figure 8 generated by making the two assumptions indicated. In comparing the two figures, it can be seen that Figure 9 has reduced the rate of decrement at the 90 to 99 percent interval while increasing it at the 30 to 39 percent interval. It is in fairly good accord with the remaining lines of Figure 8.

Inspection of Figure 9 suggests that the loss in detection is complete within 60 min and that on the average the amount of that loss of detection is 10 percent. The figure also suggests an inflection point at about 35 min, i.e. by that time almost all of the final loss has occurred. Further inspection of Figure 9 indicates that half of the final loss is completed within the first 15 min. These suggestions are in general accord with the conclusions of the

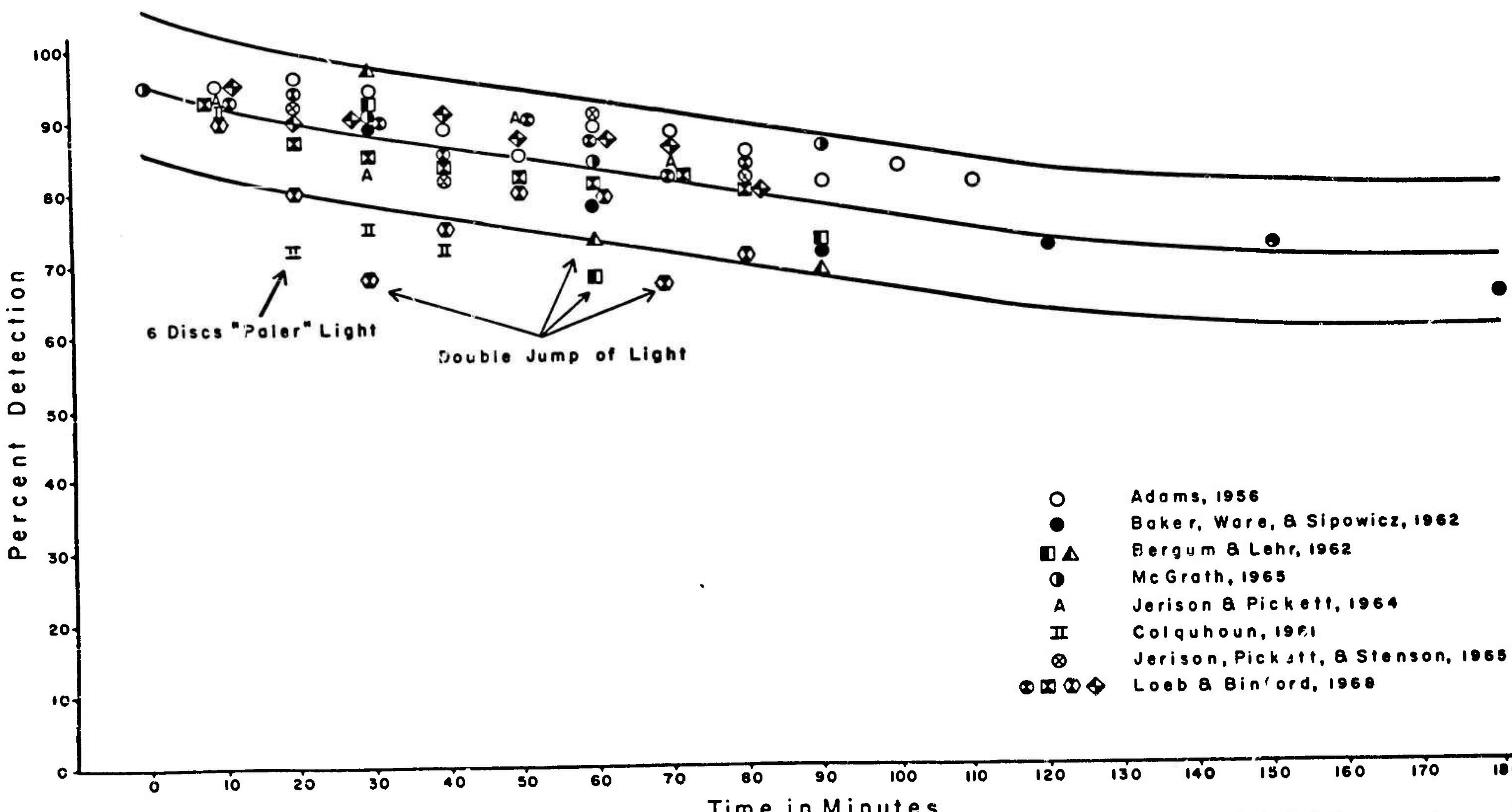

FIGURE 1. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 90 to 99.

10.b

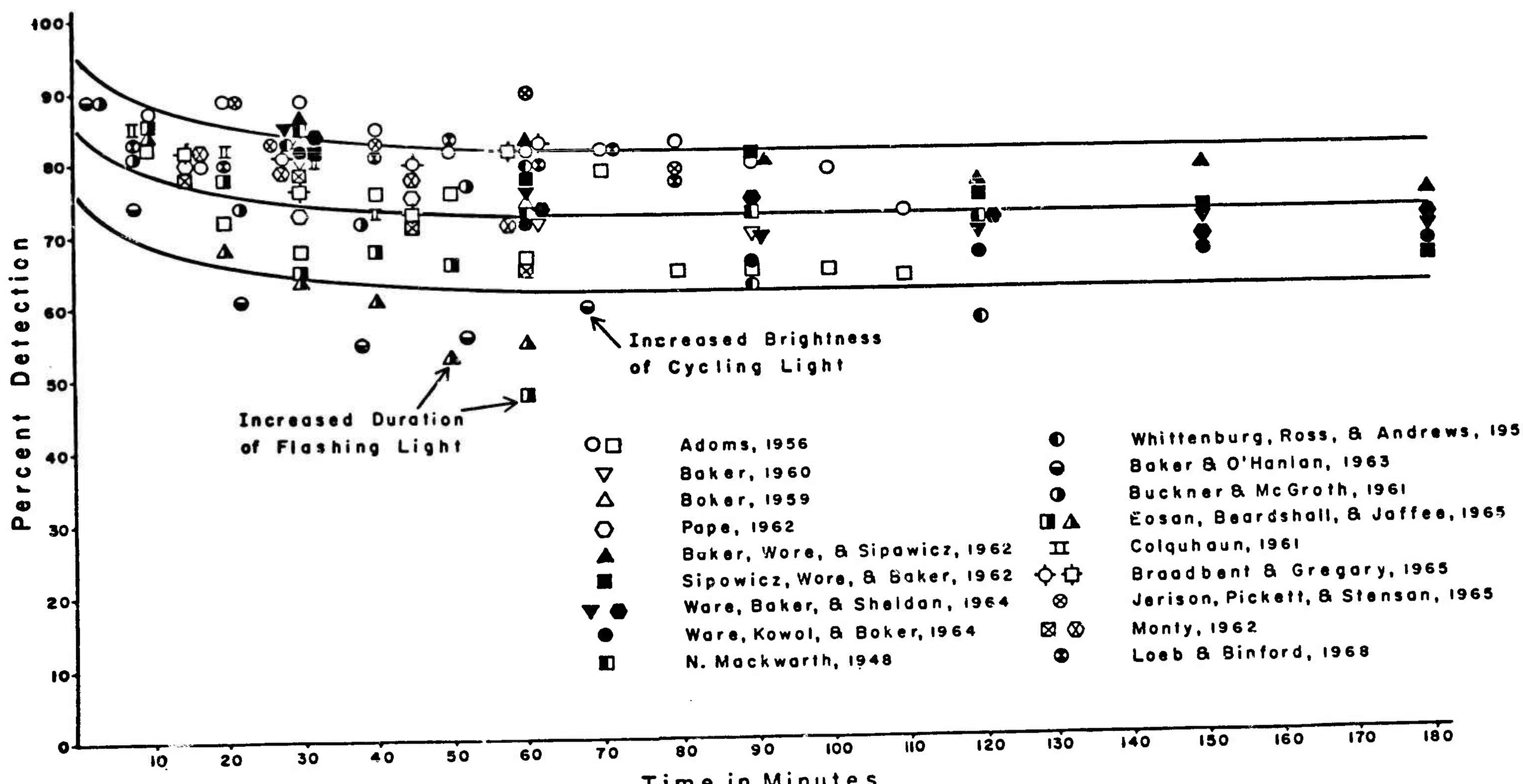

FIGURE 2. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 80 to 89.

10.C.

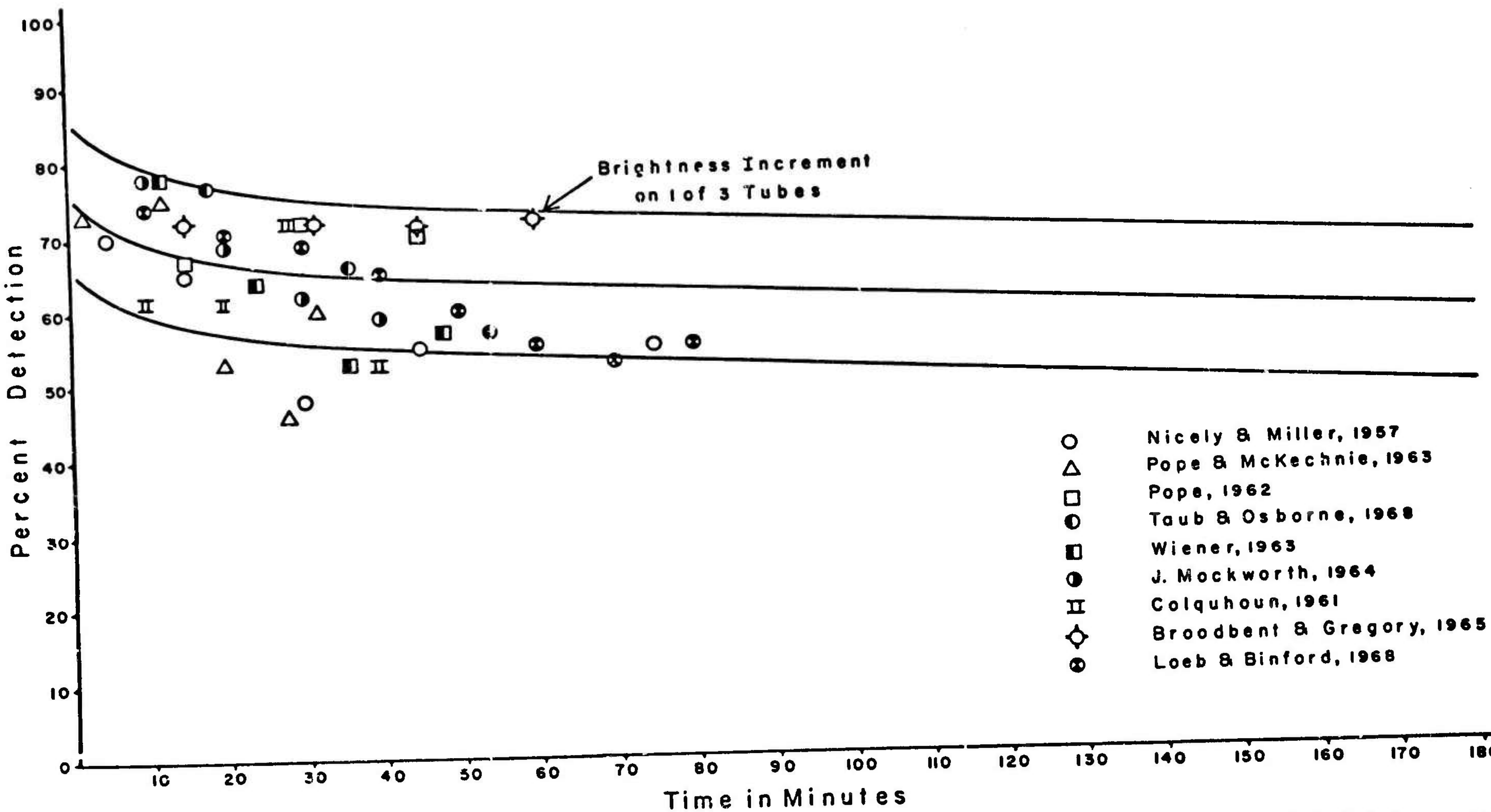

FIGURE 3. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 70 to 79.

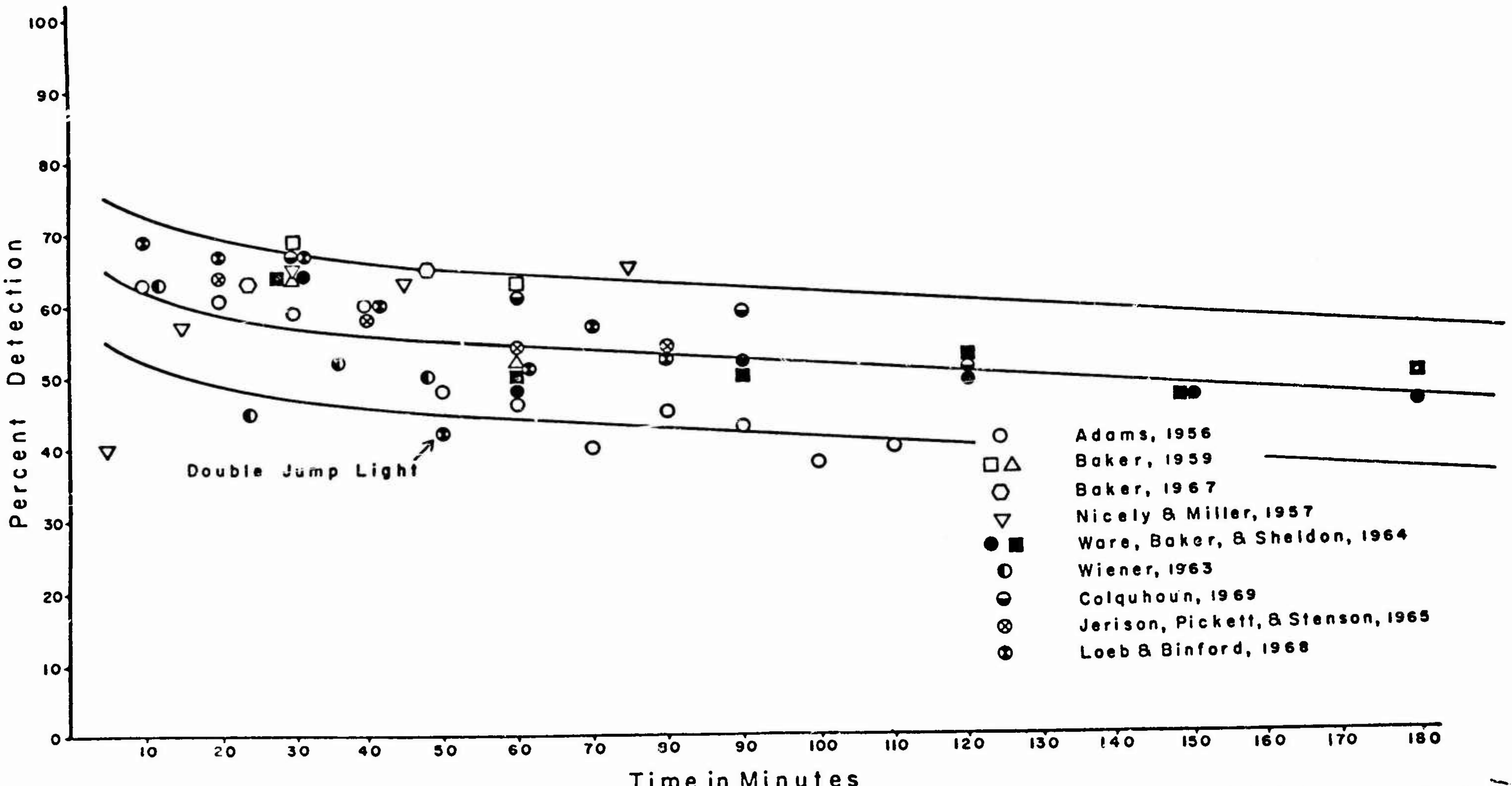

FIGURE 4. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 60 to 69.

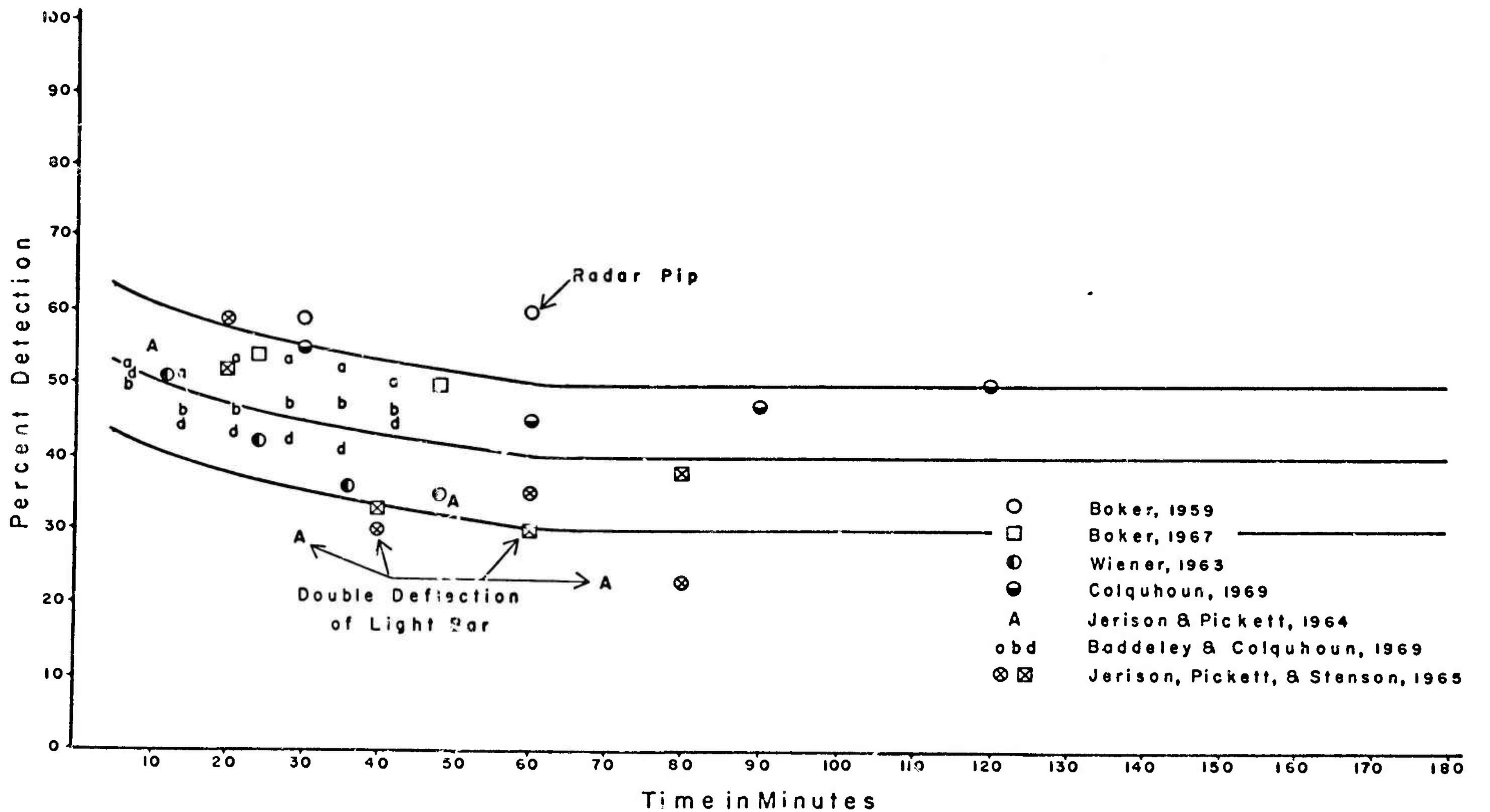

FIGURE 5. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 50 to 59.

10.8

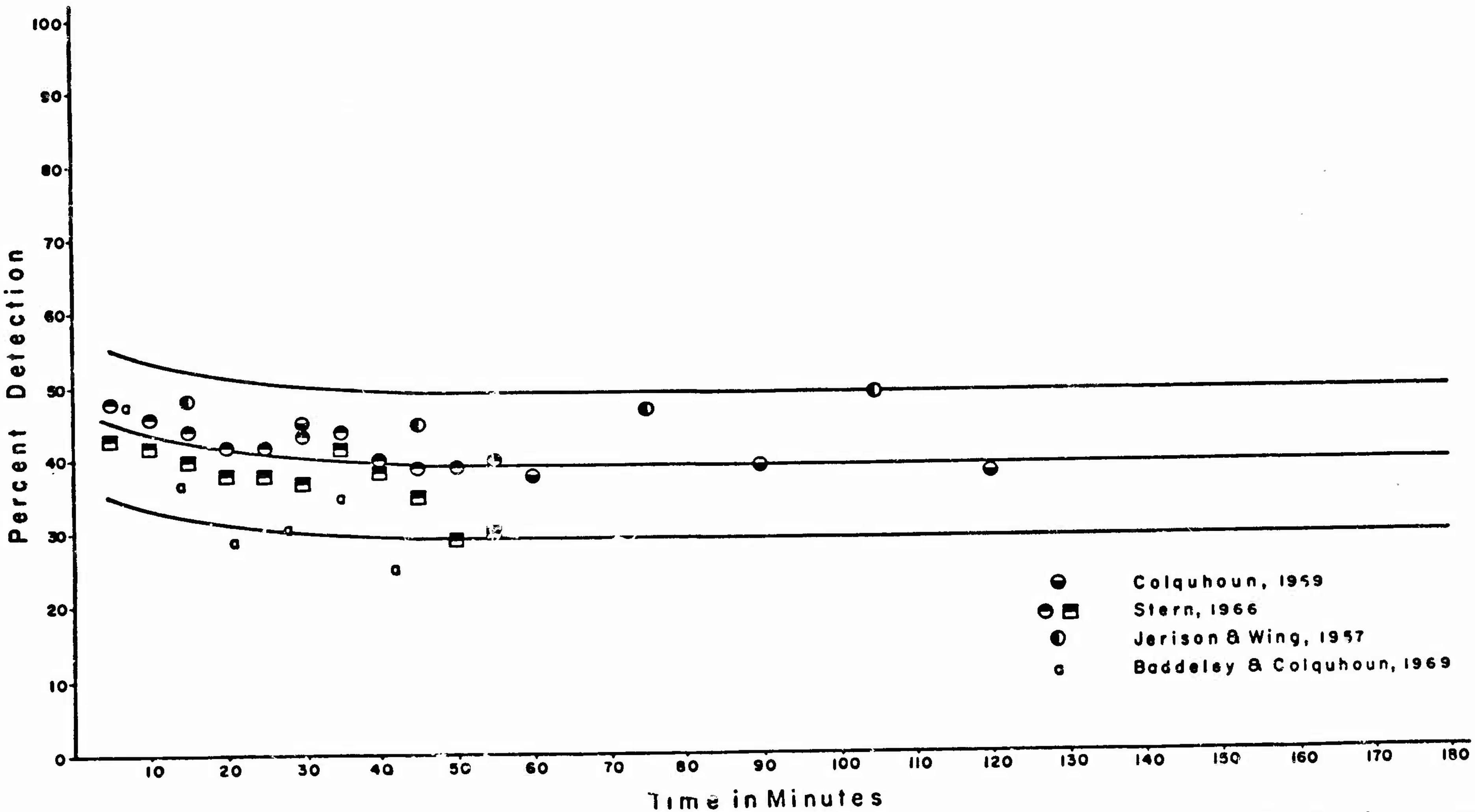

FIGURE 6. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 40 to 49.

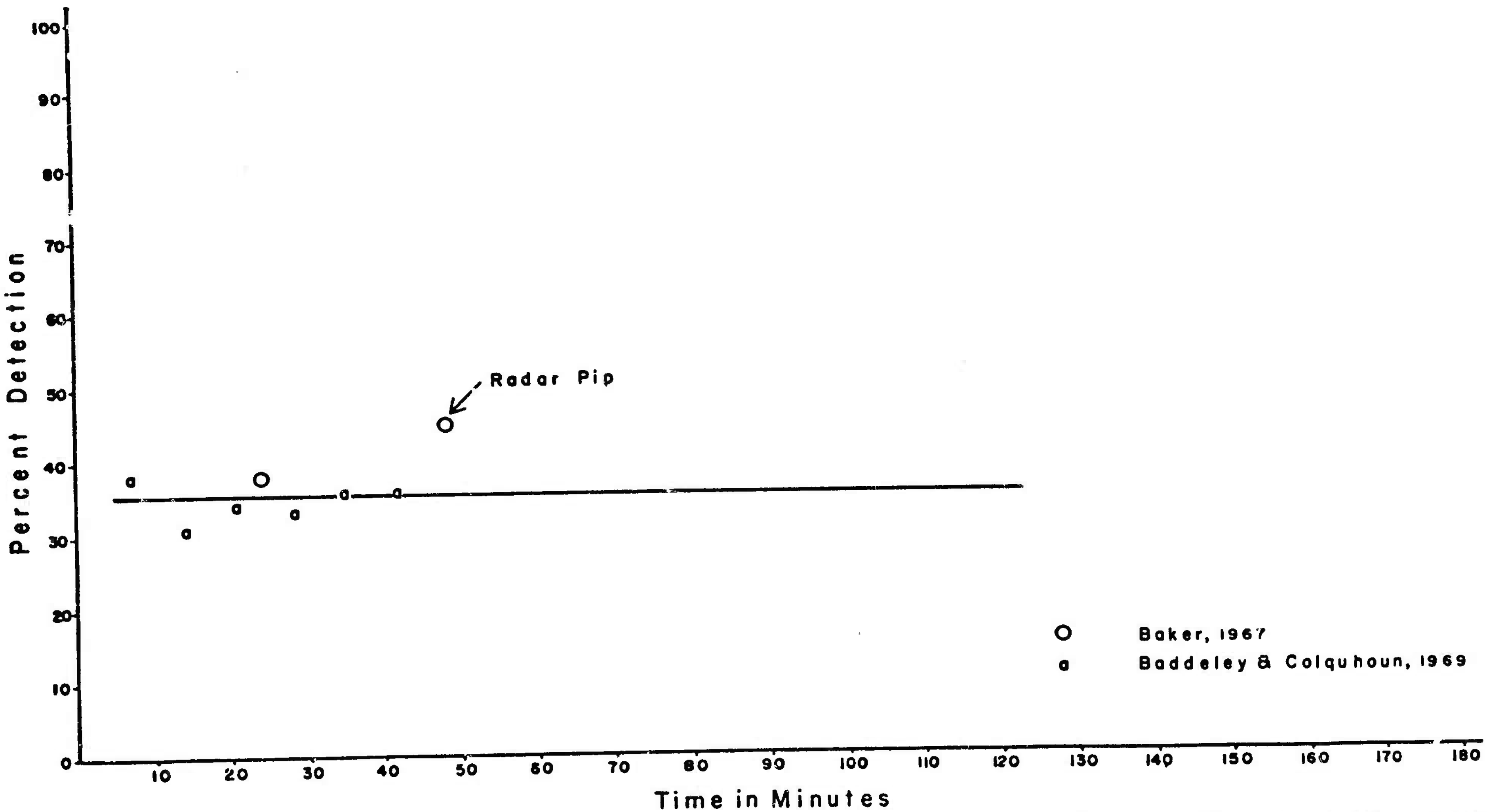

FIGURE 7. Percent detection as a function of watchkeeping time for signals having an estimated initial percentage of detection of 30 to 39.

10a

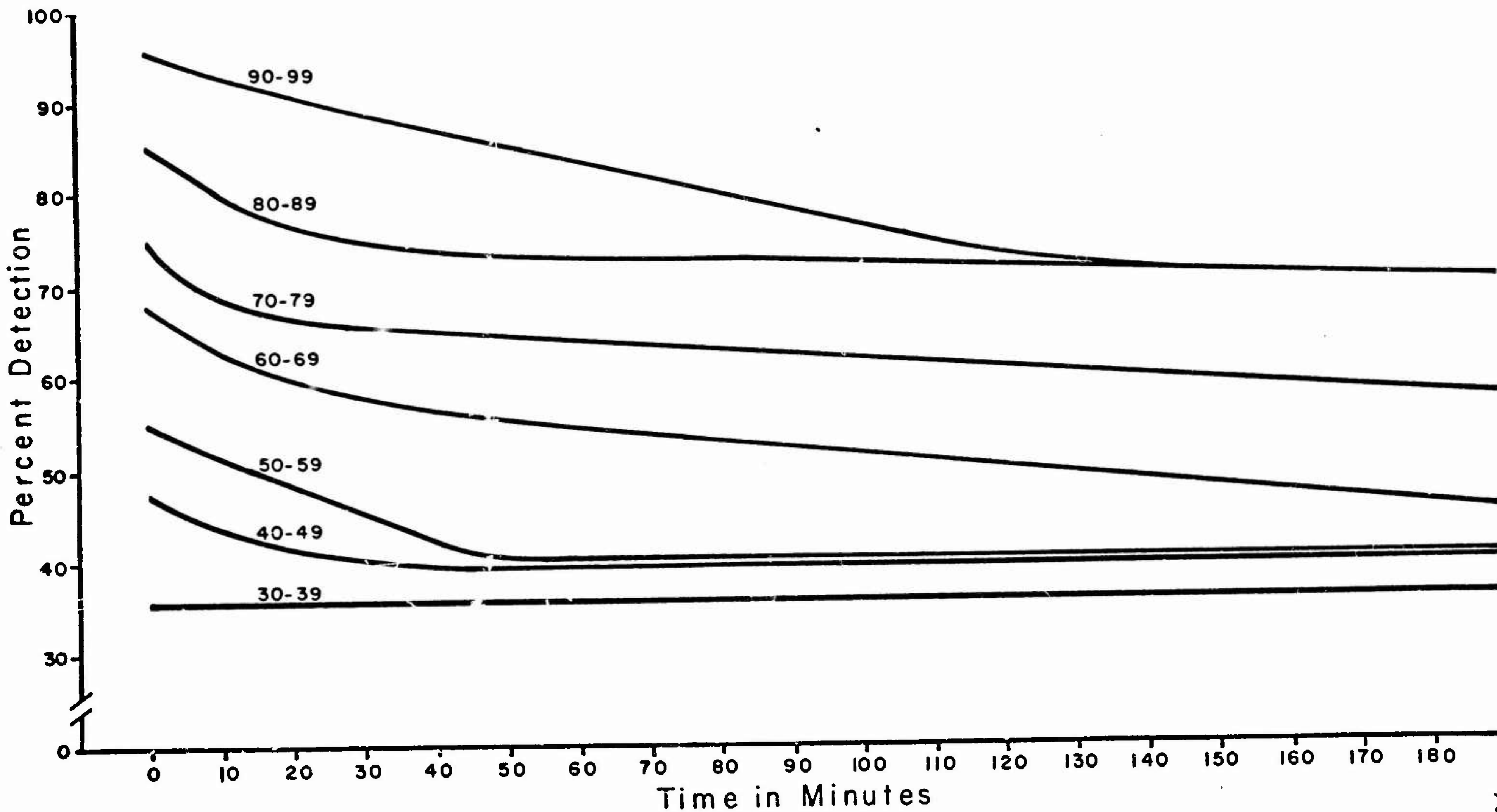

FIGURE 8. Center lines of Figures 1 through 7.

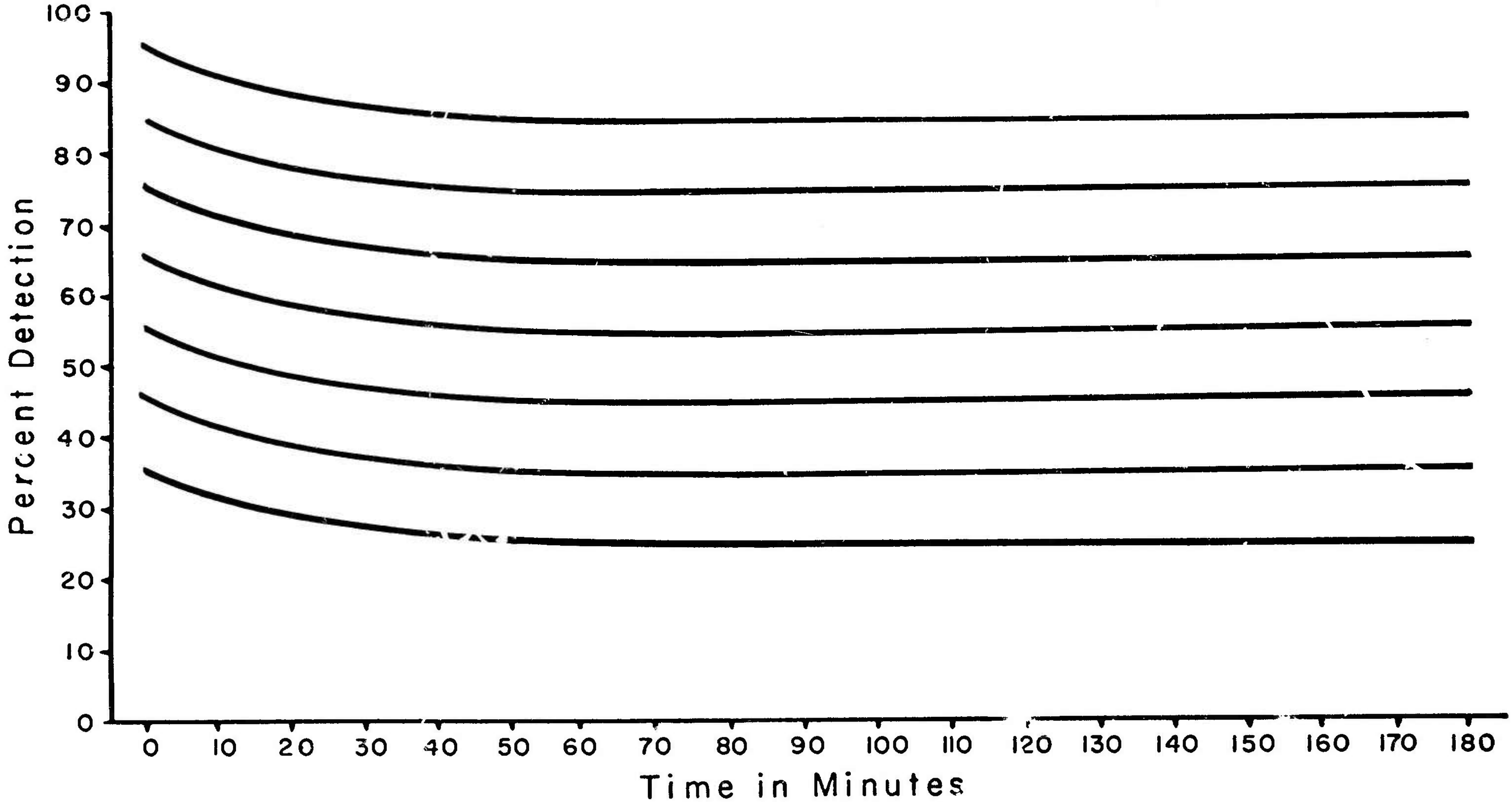

FIGURE 9. Percent detection as a function of watchkeeping time for varying initial percentage of detection. See text for explanation.

10.8

various reviewers. However, they also indicate that the absolute amount of the loss is much less than might have been anticip' from conclusions about relative changes that have been made by other investigators.

This is not to say that some studies have not shown much larger final losses than 10 percent. An inspection of Figures 1 through 6 will indicate a considerable number of experiments which have produced data of that sort. However, the same figures also show an approximately equal number of studies which produced losses of less than 10 percent. The center lines, and the idealized lines of Figure 9 therefore, represent an average effect.

Based on Figure 9, 10 percent represents the amount on the average that detection might change with length of watch. That being the case, any single set of data which deviated from the center line more than that amount at any point in time would be deviating more than the variation to be expected in association with the main variable, duration of watch. It would be reasonable, therefore, to set up significance boundaries representing that variation and, then, if any of the data were to exceed those boundaries, to infer the operation of another major variable. This is actually a very conservative criterion since a much smaller boundary range would probably have statistical significance. Use of a smaller boundary having statistical properties does not seem meaningful in the present instance, however, since the total variation to be expected is so small.

Figures 1 through 7 express the 10 percent criterion boundaries as the outer two lines of each figure. Each line is drawn parallel to the center line. The boundaries represent a deviation of +10 percent for the uppermost line and -10 percent for the lower line. Thus, the boundaries in the figures provide a total range of 20 percent. This range is actually twice that suggested by Figure 9 and slightly less than the largest change shown in Figure 8.

The studies within the boundaries have a large variability in signal rates, durations, etc. and they include all of the experimental tasks listed in Table 1 except for the sweep clock task. We are not suggesting that there could be no variations of data within the boundaries which might not have statistical significance, but that even if statistical significance should be attained, the absolute effect on the percentage of detections would have to be very small relative to the effects of IPD and of watchkeeping time. In fact, for the data shown, there is not enough inter-experiment consistency to allow for interpretable analyses within the boundaries.

There are instances within Figures 1 through 6 where there is a loss greater than the lower boundary of the figure. It may be seen that in some of those cases the loss was temporary, i.e. that there was a subsequent recovery of performance. In some other instances, there are similar losses, but without a subsequent recovery. In every one of the latter cases, the signal source was one which required a greater visual activity than generally characterized those studies which never exceeded the lower boundary. Most, but not all of the data sets which showed a greater loss, but then recovered were of that kind as well. In addition, as noted above, data from studies using the sweep clock were excluded from Figures 1 through 7 because the losses reported were usually far in excess of any other reports.

The kinds of visual activities represented by the deviant data of Figures 1 through 6 appear to fall into two classes: (1) those studies which require some form of visual pursuit tracking; the form includes following a rotating clock hand, especially the sweeping hand not plotted in these figures, and following the movement of an oscillating pointer; (2) those studies which require that the eye be aimed successively at potential target positions in space such as in the six-disc task, and (3) those studies which used flashing or cycling lights for which the signal was an increased brightness or duration. The first two kinds of experimental situation require a more or less continuous eye moving activity. The third experimental situation is one which imposes rapid changes in the status of visual adaptation. All three may be viewed as imposing a task stress which is in addition to the watchkeeping requirement. If the lower boundary line of the figures is used to represent the maximum variation to be expected as a result only of watchkeeping time, then the additional losses represented by the deviant points represent the effects of what might be called "visual fatigue." In a general way it might be useful to distinguish between static and dynamic vigilance signals where dynamic stimuli are those imposing rapid changes in the state or position of the eye whereas static stimuli do not.

The effect of stimuli which require visual tracking should depend upon the event rate. It should also depend upon the duration of the signal. Data for evaluating those two hypotheses were meager. The worst case, i.e. the sweep clock hand should provide the clearest answers to this question since that task would seem to impose the greatest tracking requirement. Accordingly, the data available based upon that device were plotted in Figures 10 and 11.

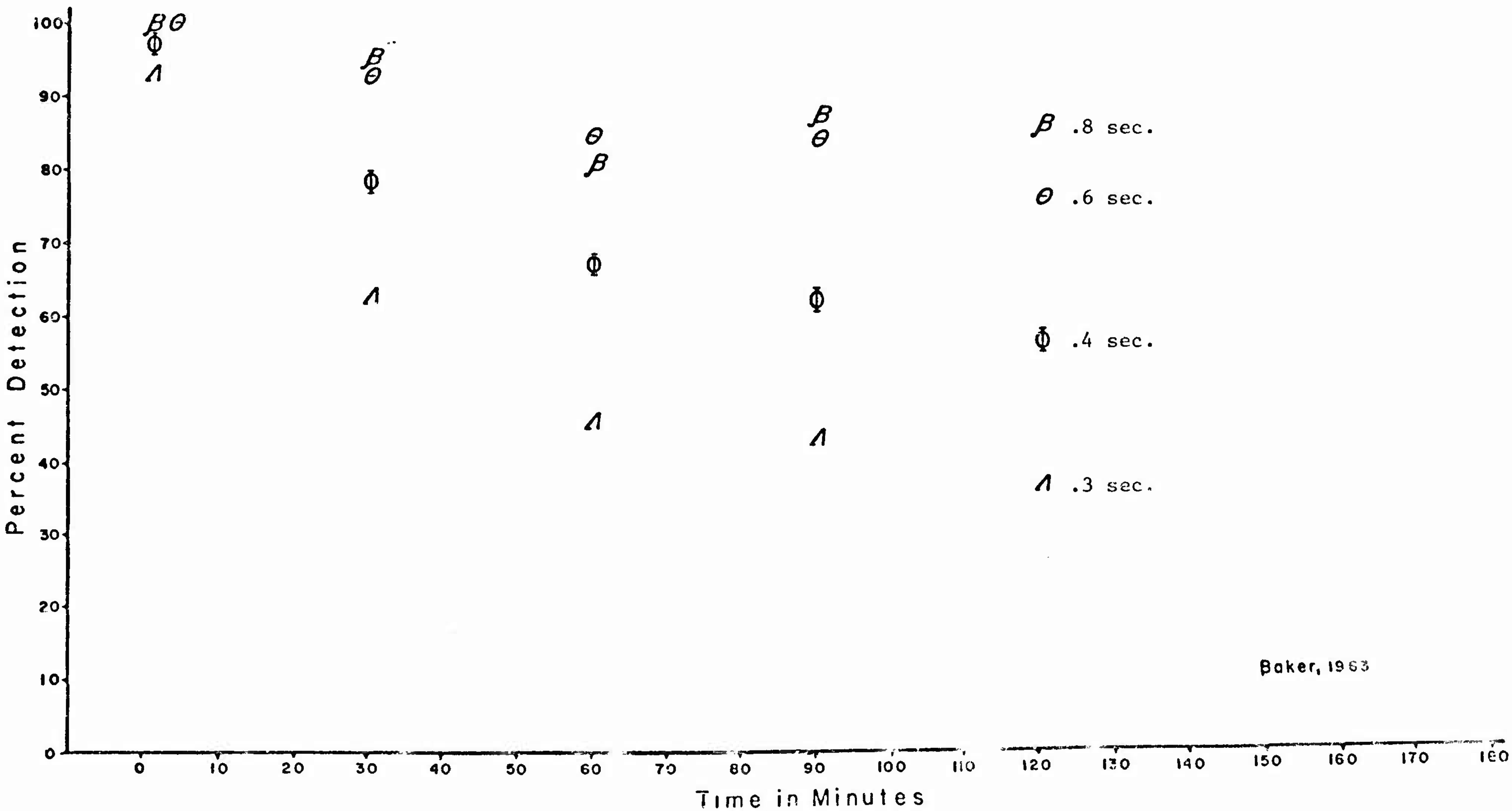

FIGURE 10. Percent detection as a function of watchkeeping time with signal duration as the parameter.

12.b

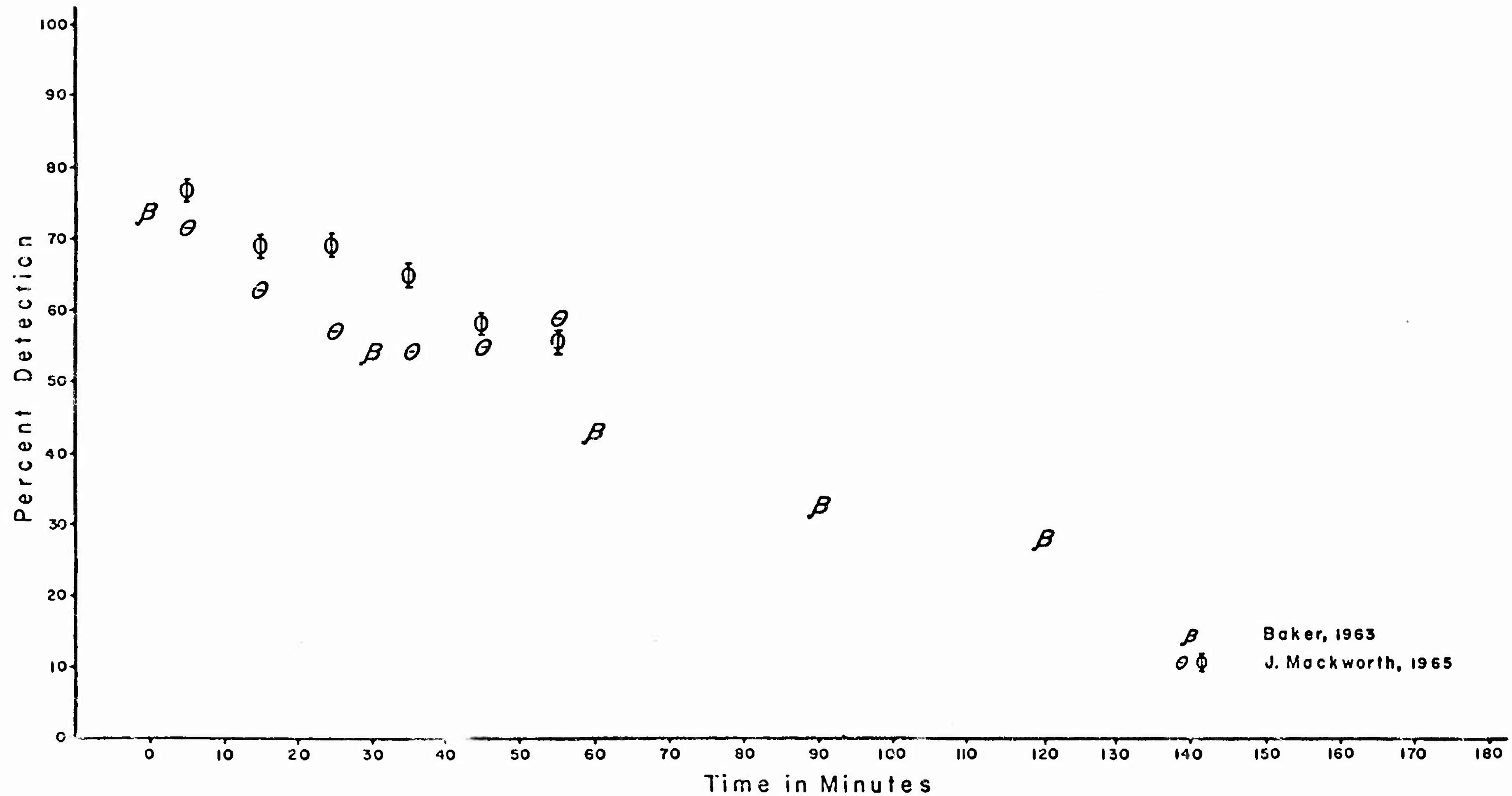

FIGURE 11. Percent detection as a function of watchkeeping time with signal rate as a parameter.

12.c

Figure 10, based entirely on the results of Baker (1963), represents a clock hand sweeping at the rate of one revolution per sec with a signal rate of .33 signals per min. It may be seen that duration of the signal was a very important variable. The losses in performance exhibited were very large for the shortest two durations of the figure. The two upper trends, those for durations of .6 and .8 sec, however, stay approximately within the lower 10 percent boundary except for the last point of the .6-sec duration, which is about 10 percent less than that boundary (i.e. using 98 percent as the IPD for these data)

Baker also used a .2 sec duration condition. The results he obtained are shown in Figure 11 where they may be compared with data from two experiments by J. Mackworth (1963, 1965). Note that all three data sets represent pre-test levels within the 70 to 79 percent interval. Thus, they could not have been compared with the data shown in Figure 10.

The three experiments whose data are plotted in Figure 11 have in common that the duration of the signal was approximately .2 sec. Mackworth's data were obtained with a signal rate of three pauses per min as compared to Baker's .33 pauses per min. It does not appear from the figure that the difference in signal rate had any effect at least up to 55 min which is the total watchkeeping time used by Mackworth. It also does not appear as if the small variations in signal duration affected the differences between experiments. In fact, the greatest resistance to decrement tended to be with the shortest signal duration. What is suggested is the possibility that Mackworth's data might asymptote at a higher level. Unfortunately, the data are not extensive enough to do more than speculate about that possibility. Thus, comparing the results of the two investigators, we can only suppose that for the duration used, approximately one hour, there was little difference between the effects of the two signal rates.

DISCUSSION AND CONCLUSIONS

The basic assumption made in the present analysis is that the pre-test detection levels could be estimated from measures obtained during the early part of the watchkeeping period. In being forced to view the first 30 min as the early part of the period, our estimates are undoubtedly in large error. Nevertheless, that procedure was the only one we were able to develop which

imparted any consistency at all to the data available in the literature. We suspect that the error is less likely to be in the assignment of studies to pre-test levels, and more likely to be in regard to the absolute values of the pre-test measures. Our use of class intervals may have reduced both possible errors somewhat.

A second assumption made was that practical significance could be established for this problem area by establishing boundaries representing the total variation to be expected as a result of the main treatment variable, time of watch. This does not imply that variations within those boundaries do not represent effective variables, but rather that those variables have very small effects compared to others which produce effects greater than the critical boundaries.

On the basis of these two assumptions and the subsequent analysis, there appear to be three major factors which influence the probability of detecting a visual signal as a function of time of watch: (1) the initial percentage or probability of detection, i.e. the normal or pre-test level, (2) the duration of the watch, and (3) whether the signal-eye relationship is static or dynamic, i.e. whether it produces or demands continuing changes in state or positon of the eye (dynamic) or does not (static). In addition, the results of Baker (1963) suggest a systematic quantitative effect of signal duration. Although, the literature is meager with respect to this variable, it would seem necessary that duration be an effective variable within some limits for both static and dynamic cases. At least it can be argued that if the duration of the signal were indefinite, sooner or later the subject would detect it. However, this variable, along with signal and event rates, is badly in need of study for the kinds of signal-eye relationships.

There appears to be a justification for viewing the static condition as representing the purer vigilance process. Theoretical approaches which invoke activation or inhibition or motivation as concepts would seem to be more reasonably tested in this experimental context. On the other hand, the dynamic situation probably represents the practical case more frequently and, as suggested by this study, it also represents the greater decrement. Perhaps an experimental approach which uses both can be devised to separate the effects of continued visual activity from those of vigilance as such and, thereby, to develop really useful principles of monitoring performance.

Finally, although the accuracy of the IPDs developed in this study may be

questioned, it does seem reasonable to conclude from them that a large amount of the inconsistencies among the available studies has been due to a failure to specify pre-test levels or to specify them accurately and in terms of the test situation to be used. How that can best be done should be a matter of importance for future efforts. Similarly, problems noted earlier concerning the frequency with which measures are obtained and the effects of practice should be studied at least with the intention of standardizing them for experimental purposes.

As a final comment, two observations appear to be in order. First, we tried above to point to the importance of controlling the interaction between practice and motivation and suggested that there is probably only a fairly small amount of practice permissible before the subject's motivation decreases. For theoretical purposes and to study selected variables, this kind of control would seem to be very important. On the other hand, radar and other observers get a large amount of practice on the job. Consequently, if immediate generalization to practical situations is what is desired, then a large amount of practice in the experimental situation is in order. Secondly, but in regard to the divergence between operational and laboratory practices in this area, it is worth noting in Table 1 that we could locate only two acceptable data sets using radar simulation. One used an IPD within the 30 to 39 percent interval (Figure 5). In neither case was there a decrement in performance with time.

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